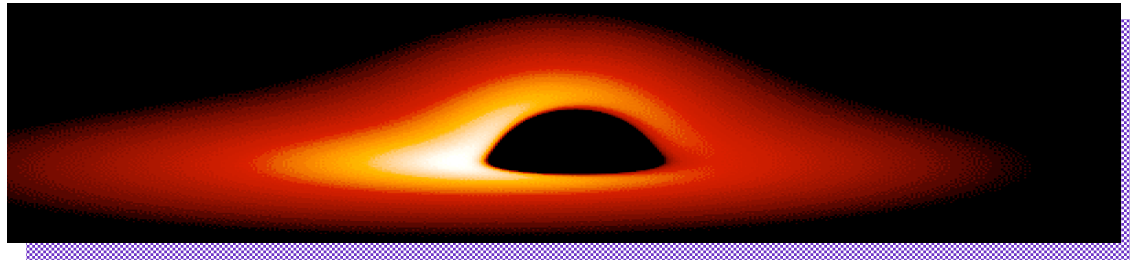


A Monte Carlo Treatment of Radiation Transfer in Black Hole Accretion Disks



Christopher Mauche



Duane Liedahl



Benjamin Mathiesen



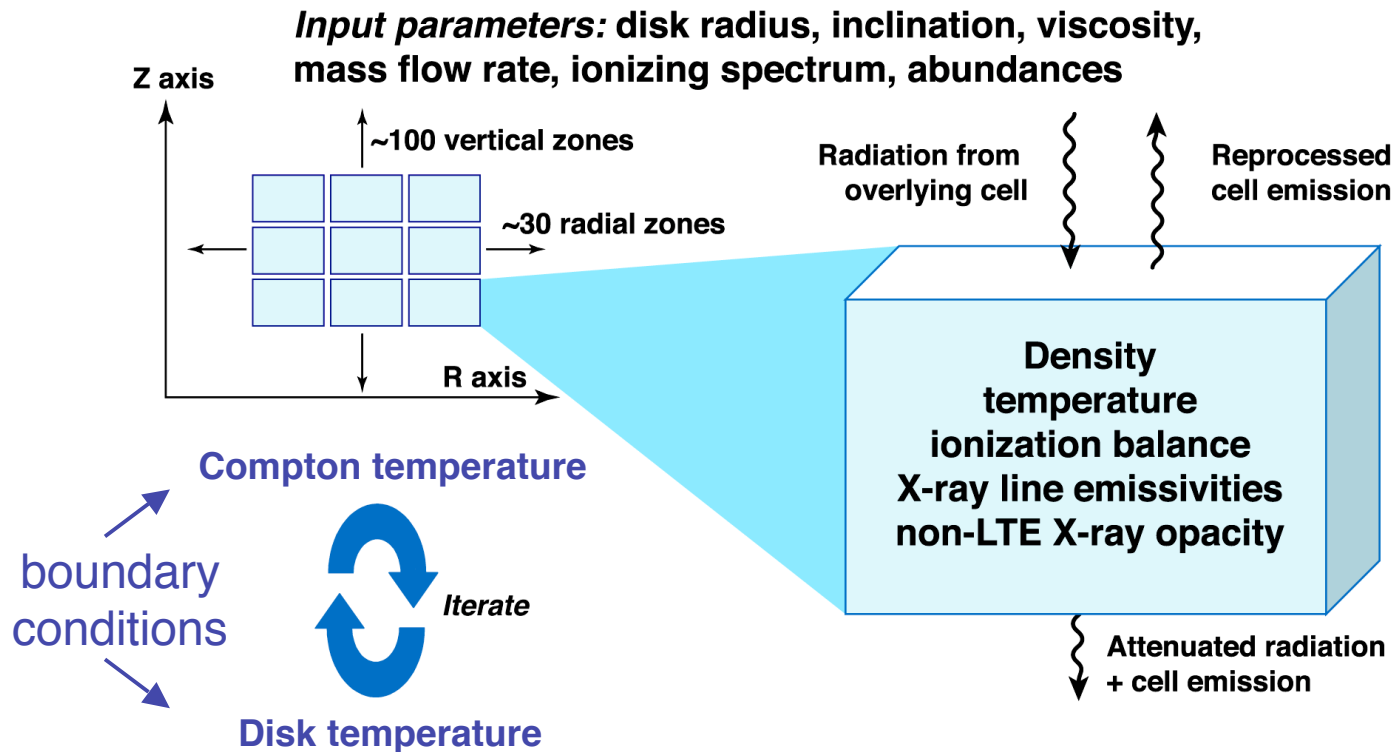
Mario Jimenez-Garate



John Raymond



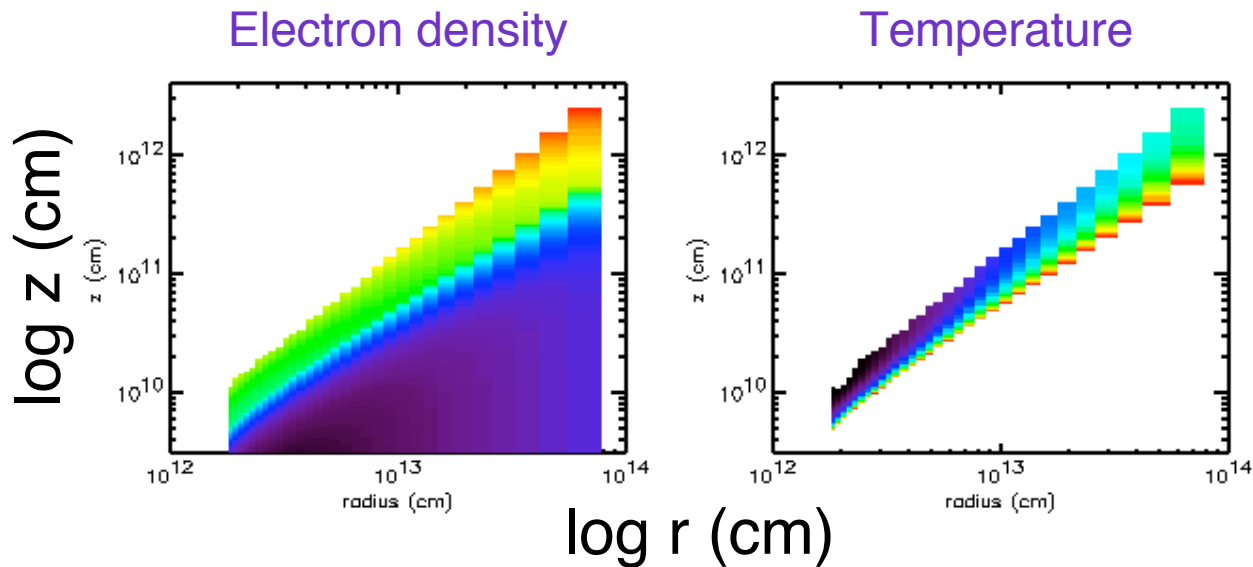
Calculation of 2-dimensional disk structure



Jimenez-Garate, Raymond, Liedahl, & Hailey (2001, *ApJ*, 558, 448)

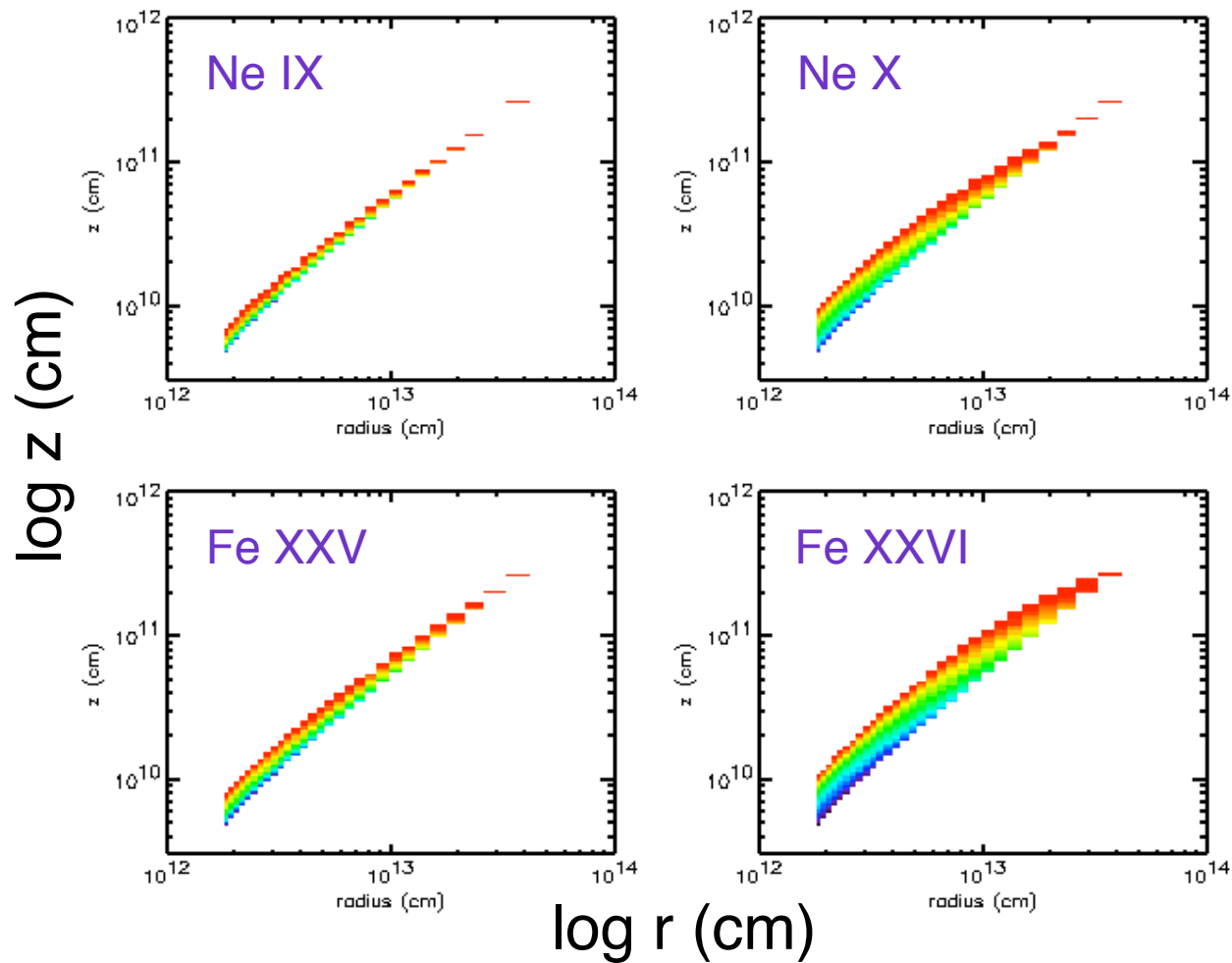
Jimenez-Garate, Raymond, & Liedahl (2002, *ApJ*, 581, 1297)

Structure calculation provides the conditions for the Monte Carlo calculation



- Monte Carlo code can be configured to track:
 - Photons coming in from above (external irradiation) ★
 - Photons coming up from below (from the accretion disk)
 - Thermal bremsstrahlung continuum photons
 - Recombination radiation lines and continua ★

Representative Lyman α line emissivities

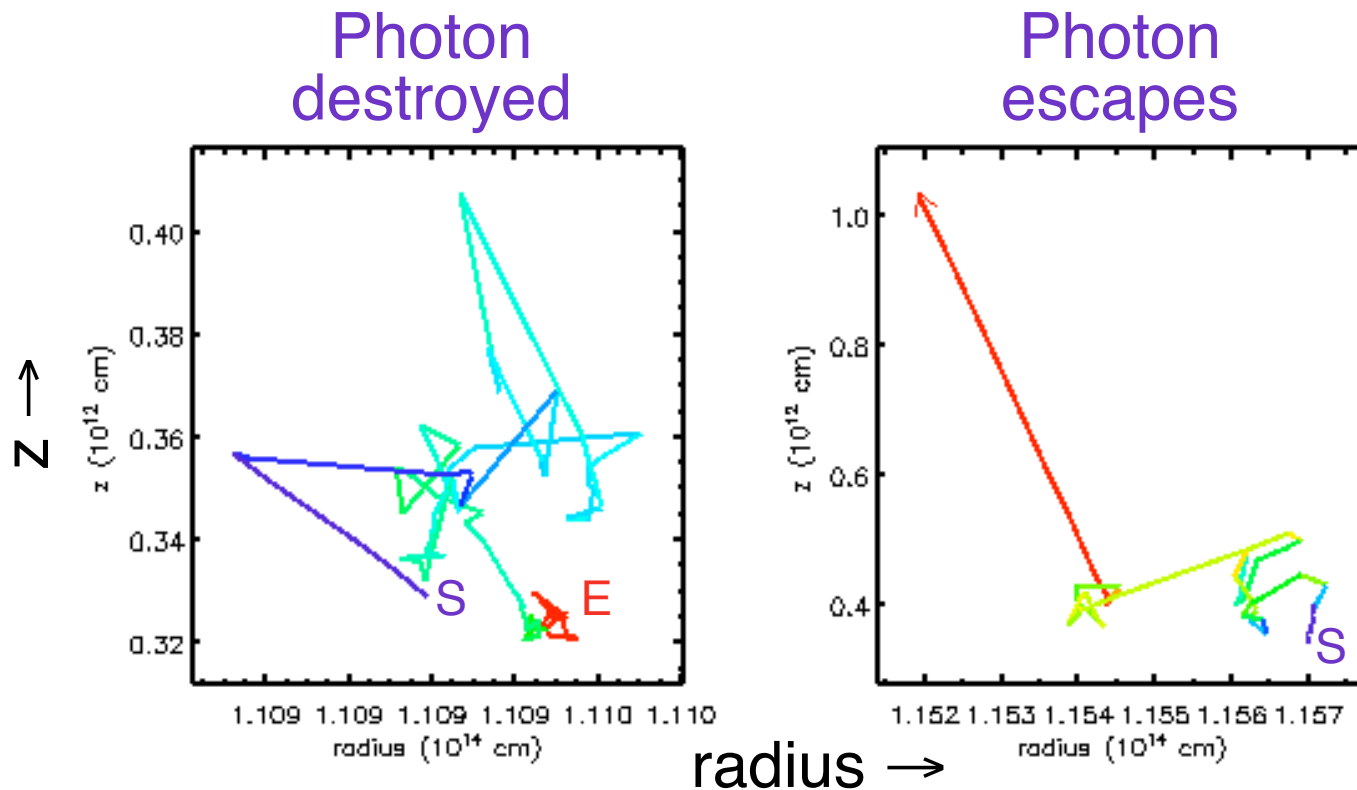


Code accounts for:

- Compton scattering by Maxwellian electrons:
 - $\Pi_{final} = Q(\Delta\theta, \Delta\phi) \cdot [R_{e\phi}^{-1} R_{e\theta}^{-1} \Lambda^{-1} R_{v\phi}^{-1} R_{v\theta}^{-1} R_{\Delta\phi} R_{\Delta\theta} R_{v\theta} R_{v\phi} \Lambda R_{e\theta} R_{e\phi}] \Pi_{initial} \cdot$
- Photoionization:
 - Verner & Yakovlev (1995) photoionization cross sections:
 - 446 edges of 140 ions of 12 elements
- Recombination lines and continua:
 - following photoionization of K-shell ions.
- Fluorescence lines:
 - following inner-shell photoionization of M-shell ions
 - use a fixed energy and yield regardless of charge state.

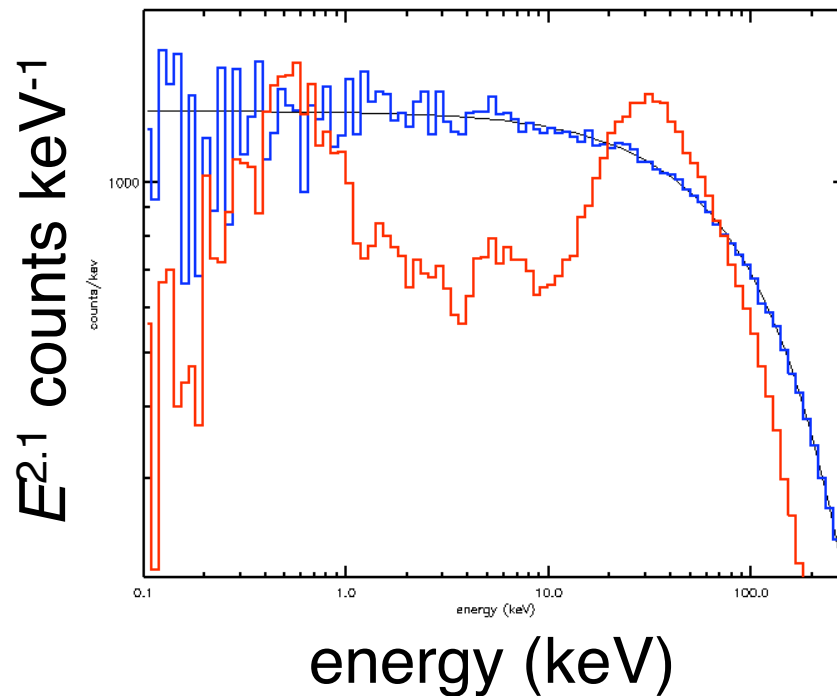


Monte Carlo code tracks the complex interactions and trajectories of individual photons



Colors encode the relative energy of the photon,
starting (S) with purple and ending (E) with red.

Case of external illumination



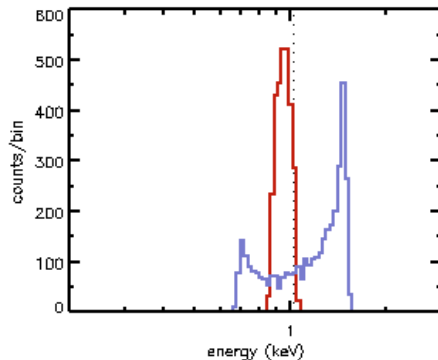
blue:
incident spectrum:
cut-off power law:
 $dN/dE = E^{-2.1} \exp(-E/150)$

red:
reflected spectrum

Reflected spectrum shows the characteristic Compton bump at ~ 30 keV and a complex pattern at low energies due to recombination emission and photoionized bound-free opacities.

Case of recombination emission: Ne X Ly α ...

Rotation
only



Ne X Lyman α
1.02 keV

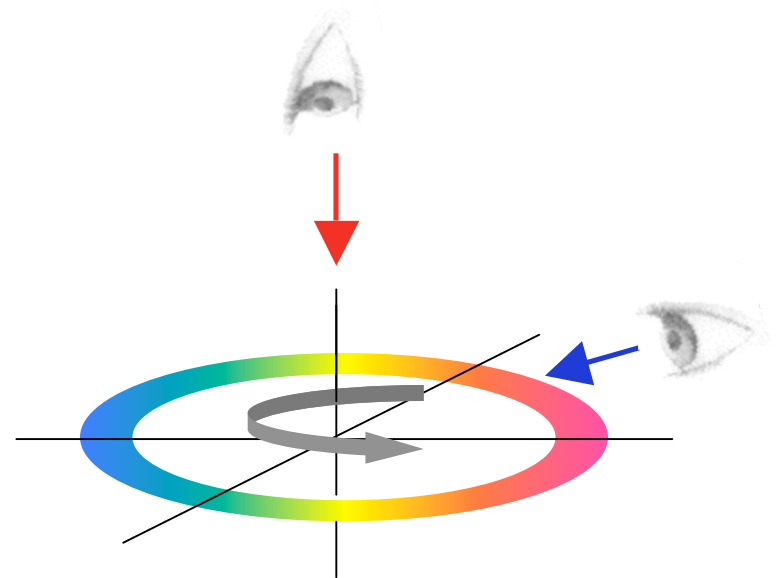
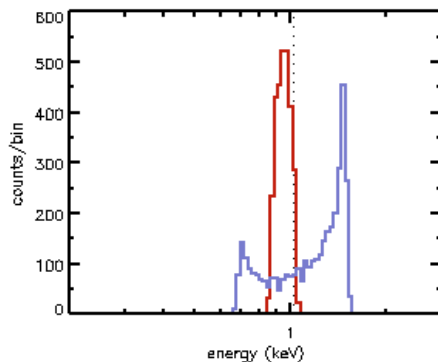


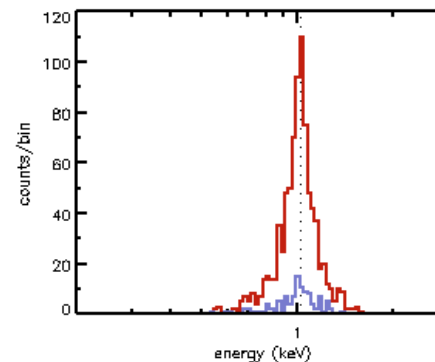
Figure shows Ne X Lyman α line profiles for observers at $i = 0^\circ$ (red) and $i = 75^\circ$ (blue). The rotation velocity $\beta = 0.37$.

Case of recombination emission: Ne X Ly α ...

Rotation
only



Compton
scattering

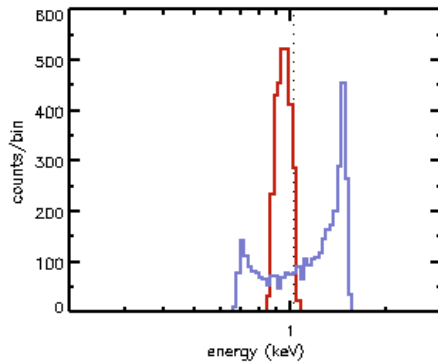


Compton scattering broadens the profiles.

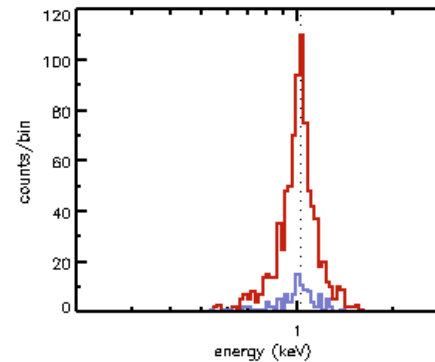


Case of recombination emission: Ne X Ly α ...

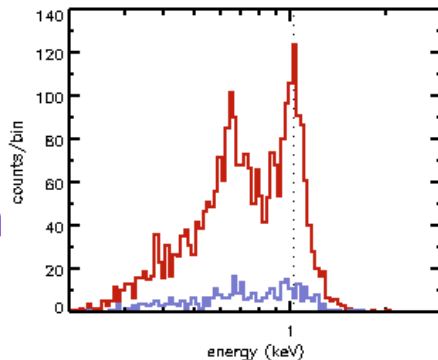
Rotation
only



Compton
scattering



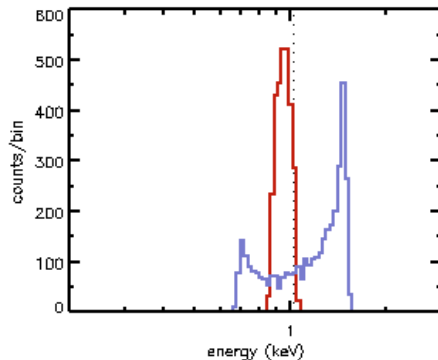
Compton
scattering
+
Recombination



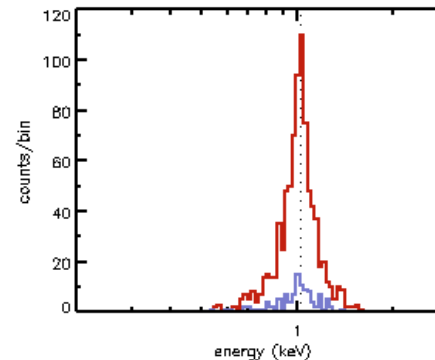
Recombination emission transforms Ne X Lyman α photons into O VIII Lyman α , β , and recombination continua photons.

Case of recombination emission: Ne X Ly α

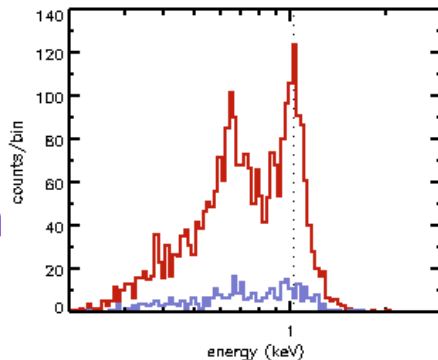
Rotation
only



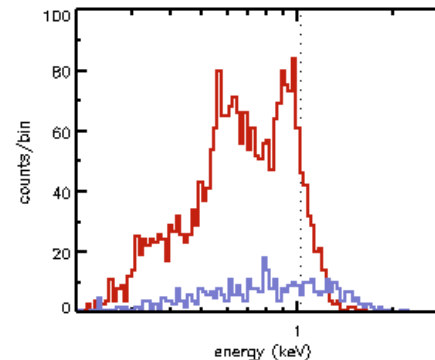
Compton
scattering



Compton
scattering
+
Recombination



Compton
scattering
+
Recombination
+
Rotation

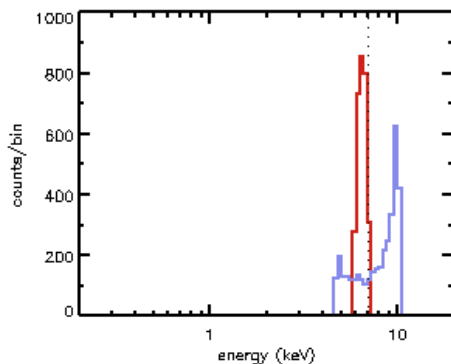


Rotation broadens the profiles, shifts the peaks to
lower (**higher**) energies for **small** (**large**) disk inclinations.



Case of recombination emission: Fe XXVI Ly α ...

Rotation
only



Fe XXVI Lyman α
6.97 keV

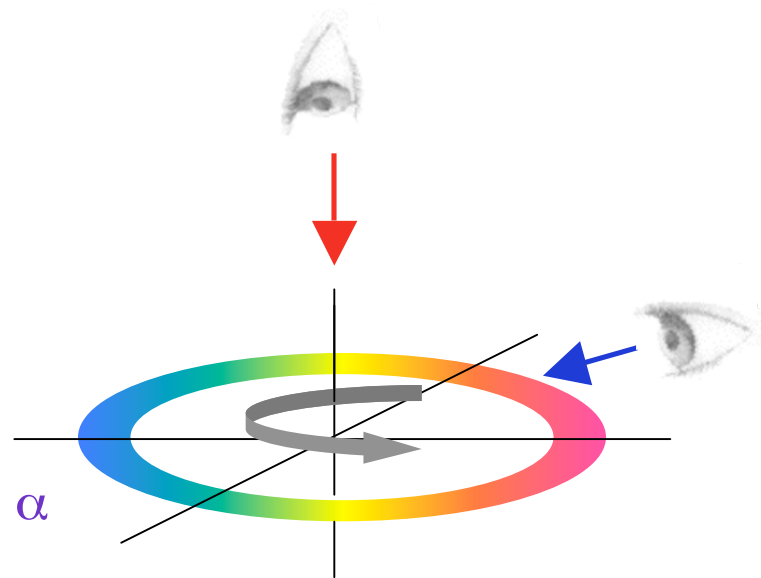
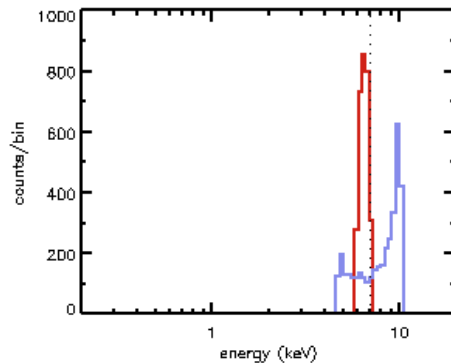


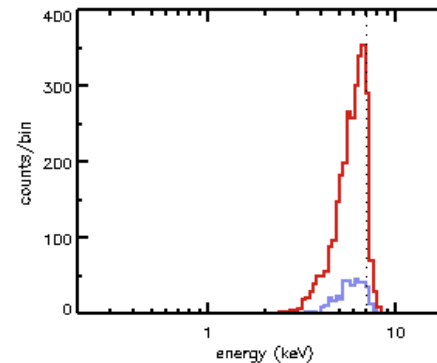
Figure shows Fe XXVI Lyman α line profiles for observers at $i = 0^\circ$ (red) and $i = 75^\circ$ (blue). The rotation velocity $\beta = 0.37$.

Case of recombination emission: Fe XXVI Ly α ...

Rotation
only

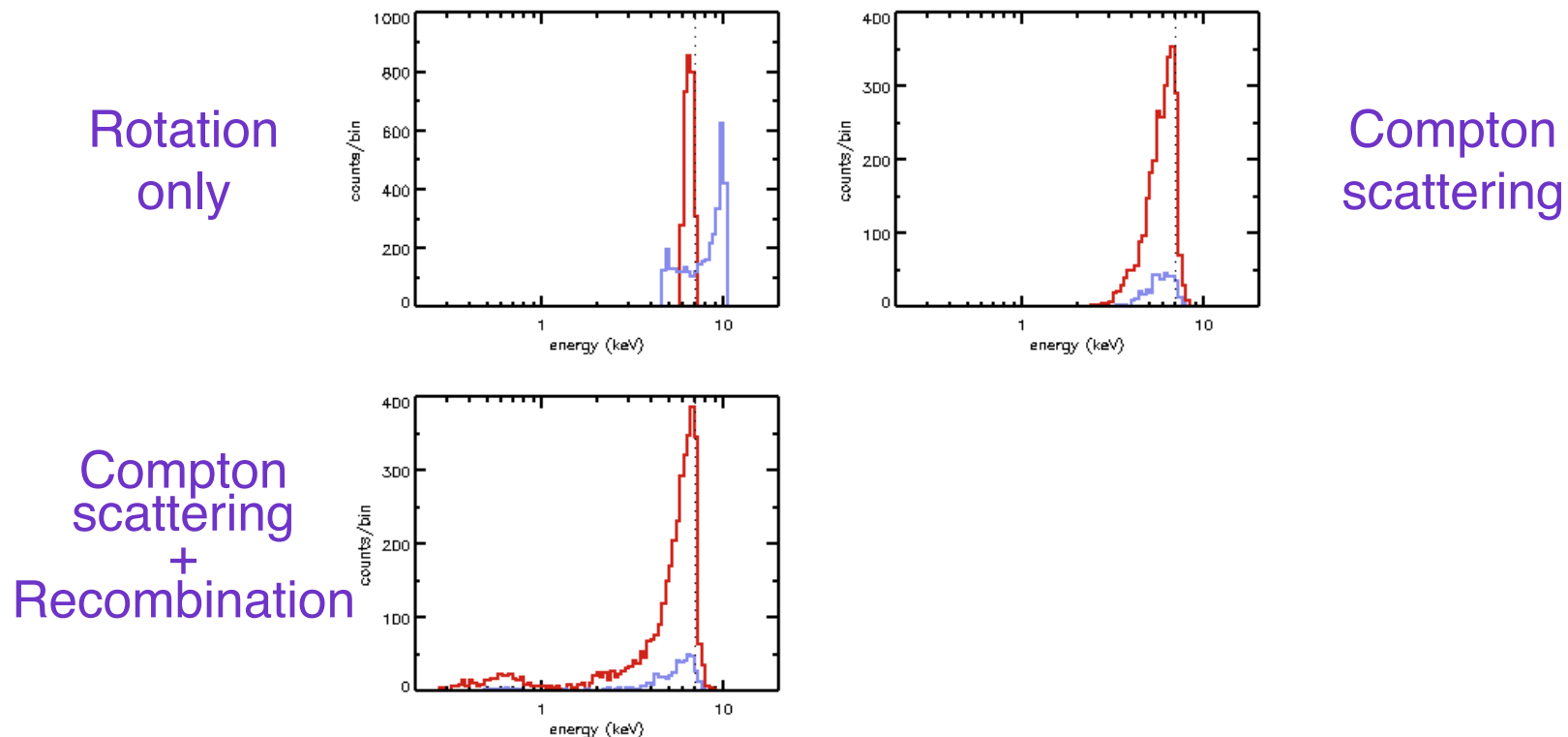


Compton
scattering



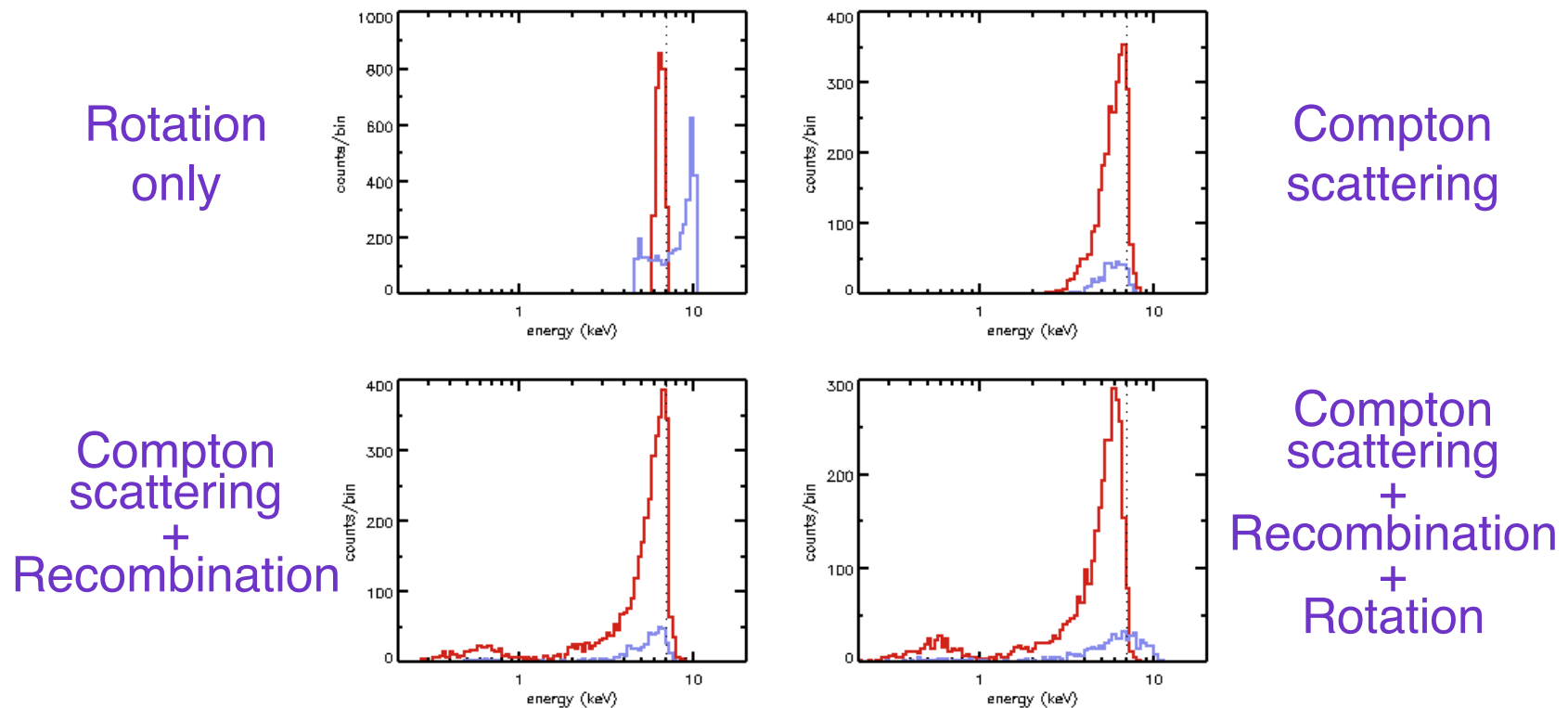
Compton scattering broadens the profiles
and skews them to the red.

Case of recombination emission: Fe XXVI Ly α ...



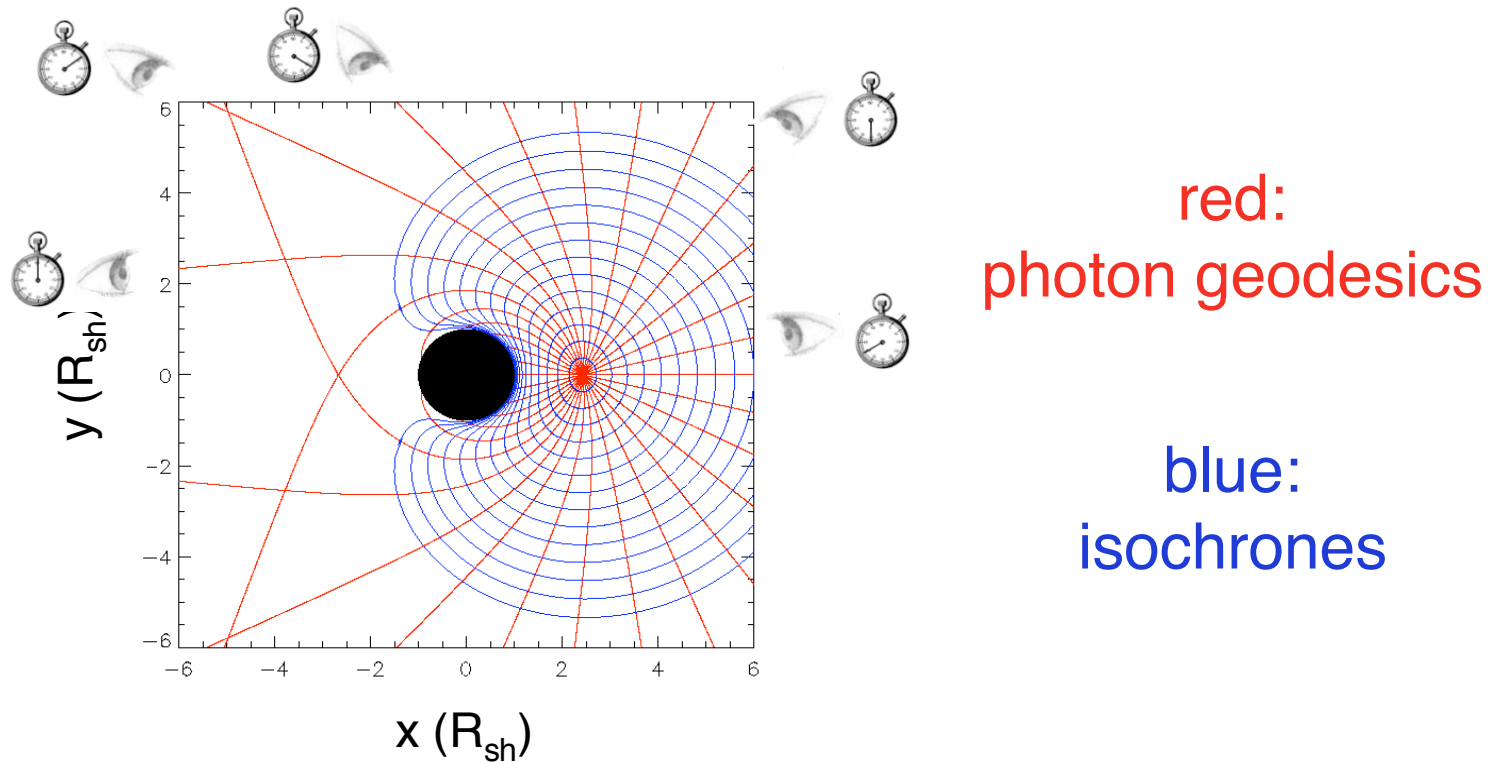
Recombination emission transforms Fe XXVI Lyman α photons into various Lyman α , β , and recombination continua photons.

Case of recombination emission: Fe XXVI Ly α



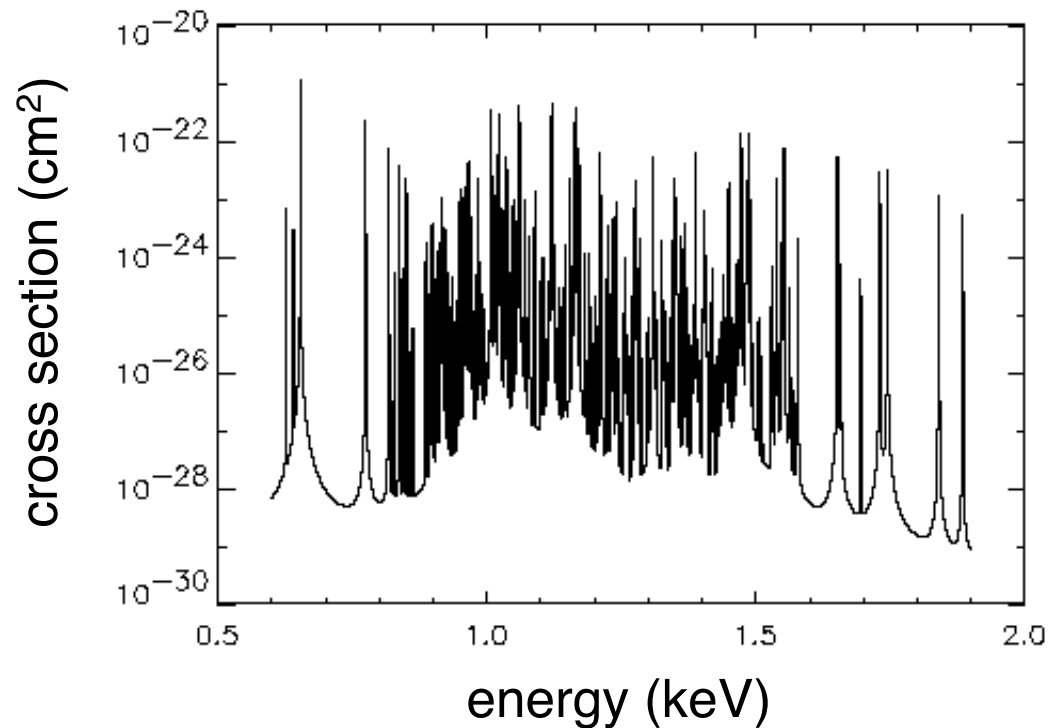
Rotation broadens the profiles, shifts the peaks to **lower** (**higher**) energies for **small** (**large**) disk inclinations.

Planned improvements to the code: 1



Add geodesic solver to account for light bending
for both Schwarzschild and Kerr black holes

Planned improvements to the code: 2



Add line opacity using LLNL atomic models

Planned improvements to the code: 3



Port to LLNL ASCI supercomputer

Auspices statement

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

